# CRACK GROWTH MODELING AND LIFE ASSESSMENT OF HIGH TEMPERATURE COMPONENTS THROUGH FINITE ELEMENT ANALYSIS

**M. Venkateswara Rao*, Dr. S. Seetharamu*, Dr. Shamasundar****
** Central Power Research Institute, Bangalore*
*** ProSIM R&D Pvt. Ltd, Bangalore (shama@pro-sim.com)*

### *ABSTRACT:*

Various methods have been developed for assessing the remaining life assessment (RLA) of critical high temperature components. Analysis of RUL is done using well established life fraction theories and creep-rupture material data bases. For heavy section components such as headers and piping which operate at high temperature, failures are characterized by the initiation & growth of crack under the influence of creep and/or fatigue. Using a combination of finite element analysis and fatigue and fracture calculations, RUL can be assessed. Authors have used commercially available software **FESAFE** for high temperature thermo-mechanical fatigue as well as creep analysis and **ZENCRACK** for 3D-non-planar crack propagation simulation.

## *1.0 INTRODUCTION:*

In conventional Residual life assessment various Non-Destructive methods such as dye penetrant inspection, magnetic particle inspection, ultrasonic test, in-situ mettallography & hardness, etc. are used. Where as in Finite Element Analysis (FEA) method the component will be modeled and service conditions will be superimposed on the model and stress analysis will be carried out in the first phase analysis. Later creep fatigue. Low cycle fatigue, crack growth analysis will be carried out using different software's. This will help in identifying the critical locations, which may not be possible with normal NDT methods.

## *2.0 FINITE ELEMENT ANALYSIS APPROACH*

Finite element software, Zencrack is a powerful tool that uses concept of 'crack-blocks' for fracture mechanics applications. The software is capable of generating fine FE meshes and studying the behaviour of 3D crack fronts under generalized mixed-mode loading.

The software uses J-integrals and an energy release rate approach for Linear Elastic Failure Mechanics (LEFM). J-Integrals include the changing state of stress along a crack front avoiding the assumptions required for calculating stress intensity factors (SIFs). J-integrals can also be evaluated for EPFM. Software also provides a Crack Tip Opening Displacement (CTOD) methodology for LEFM allowing analysis with FE codes which does not have 3D J-Integral capabilities. Crack growth directions & magnitudes are calculated using the results of energy release rate evaluations from a finite element analysis. FEA provides two levels of analysis i.e. initial crack and crack growth prediction.

In the first level of analysis for components where static loading is important, software can evaluate SIFs without crack growth. For failure assessment, both linear and non-linear analyses can be undertaken to provide the information required to generate a failure assessment diagram (FAD) as required in the R6, BS 7910 and API 579 codes.

The second level of capability provides a facility for 3D non-planar crack growth prediction based on the fatigue or time-dependent loading. FEMA predicts the magnitude and direction of 3D crack growth along each crack front and advances each crack through the FE model. Several options are available for crack growth data definition including a user subroutine capability for complex proprietary data. A flexible "load system" approach is provided for defining load spectra.

### *2.1 FEA METHODS & ANALYSIS*

FEA methods & analysis involves various stages of operations and the details are given below:

- Choice of J-integral or COD to determine energy release rates or SIFs for all crack shapes
- Modeling of 3D non-planar crack growth and the prediction of crack shape development
- Incorporation of residual stress distributions with external cyclic stress
- Breakthrough of corner-type cracks to through crack fronts
- Fatigue and time-dependent crack growth or combined time / fatigue growth
- Spectrum loading
- Time-dependent load and temperature history
- Paris and Walker crack growth equations including dependency on stress ratio and temperature
- User subroutines for crack growth data and threshold
- Basic and generalized Willenborg retardation models
- Incorporation of solid hex-element crack-blocks in a tetrahedral finite element mesh
- Rainflow counting software of raw load spectrum data
- Post-processing utilities to plot, for example, crack growth versus cycles and crack growth profiles.
- 3D structural model constrained to behave like a 2D or axi-symmetric model
- 3D crack front prediction
- Changing state of stress along the crack front
- Non-planar or mixed mode crack growth in any direction
- Crack shape development and consistent dN calculation

Adaptive meshing algorithms are integrated into FEMA to simulate crack growth by updating nodal positions in and around the crack-blocks. Crack-blocks may "transfer" to new positions to allow simulation of significant growth within a model.

On a component or task-based level the potential use of the software is almost unlimited. Typical applications include:

- Ligaments of headers in power plant boilers.
- High temperature components in power plants.
- Power generation components e.g. high pressure water box.
- Pipeline defects and connections e.g. tee sweepolet connections.
- Welded connections & so on…

Analysis methods have also been developed which consider time dependant fracture mechanics (TDFM) and that allow quantification of component life based on crack growth. A flow chart to predict the life of high temperature components is given Flow Chart 1

### *3.0 CASE STUDIES:*

The FEMA has successfully carried out on a boiler and turbine manufactured with 176 kg/cm$^2$ (2503 psi) and 541$^o$C main steam conditions 45.2 kg/cm$^2$ and 541$^o$C reheat steam conditions. The unit was placed into commercial operation in 1982 and had accumulated approximately 100,000 operating hours and 2770 unit starts ups. Locations selected for analysis included all the major plant components, namely: (a) Piping – the highest stressed girth welds in the main steam and hot reheat piping, (b) Headers – the boiler superheat and reheat outlet headers and the economizer inlet header, (c) Turbine – the HP turbine inner cylinder and the turbine chest throttle valve and governor valve bodies.

Here, are the typical case studies attempted using FEA modeling are presented:

Case Study 1 – Stress analysis carried out on the main steam piping girth weld, where the highest stress developed during service, (Figure 1)

Case Study 2 – Typical monitoring locations for header ID surface bore-hole ligament cracking are illustrated in Figure 2 for the secondary super-heater outlet header.

Case Study 3 – For the turbine, cracking at the HP turbine inner cylinder flange near the bolt holes which was removed by grinding, prompted monitoring of this location for recurrence of cracking (Figure 3).

Case Study 4&5 – Cracking in the original steam chest throttle valve (TV) and governor valve (GV) bodies prompted replacement of the entire steam chest, and monitoring at the TV seat fillet radius (Figure 4) and the GV seat fillet and outlet transition radii (Figure 5) locations known to be susceptible to crack initiation was implemented after steam chest replacement.

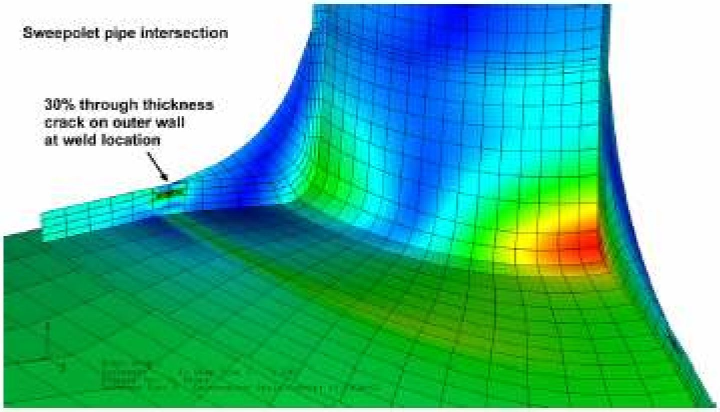


Figure 1 Crack shown at weld location

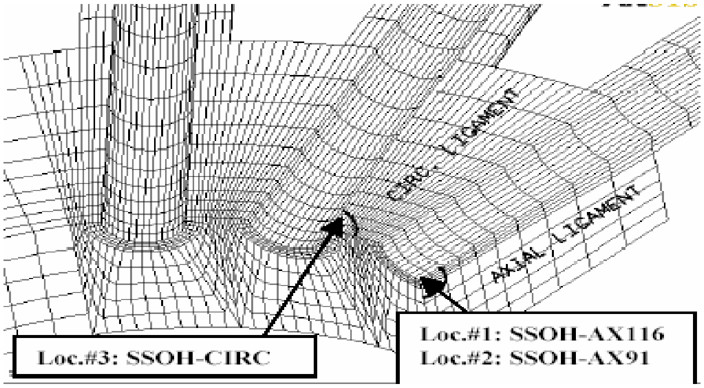


Figure 2 - Super heater outer ligament cracking locations

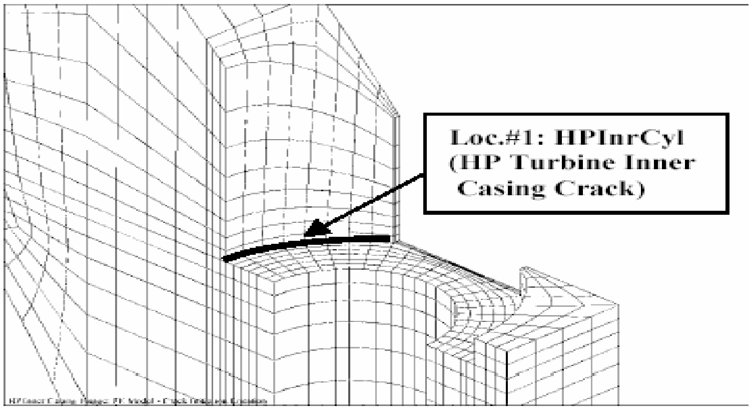


Figure 3 - Inner cylinder Flange cracking location

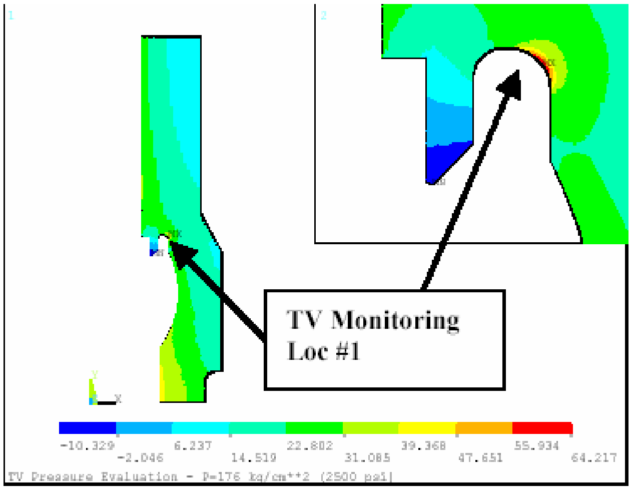


Figure 4 - Throttle valve body ID surface cracking location

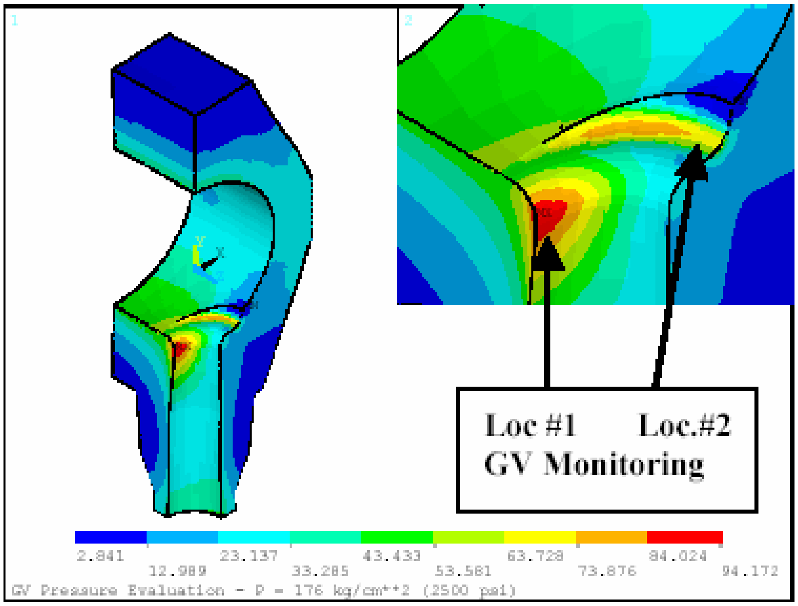


Figure 5 - Governor body ID surface cracking location

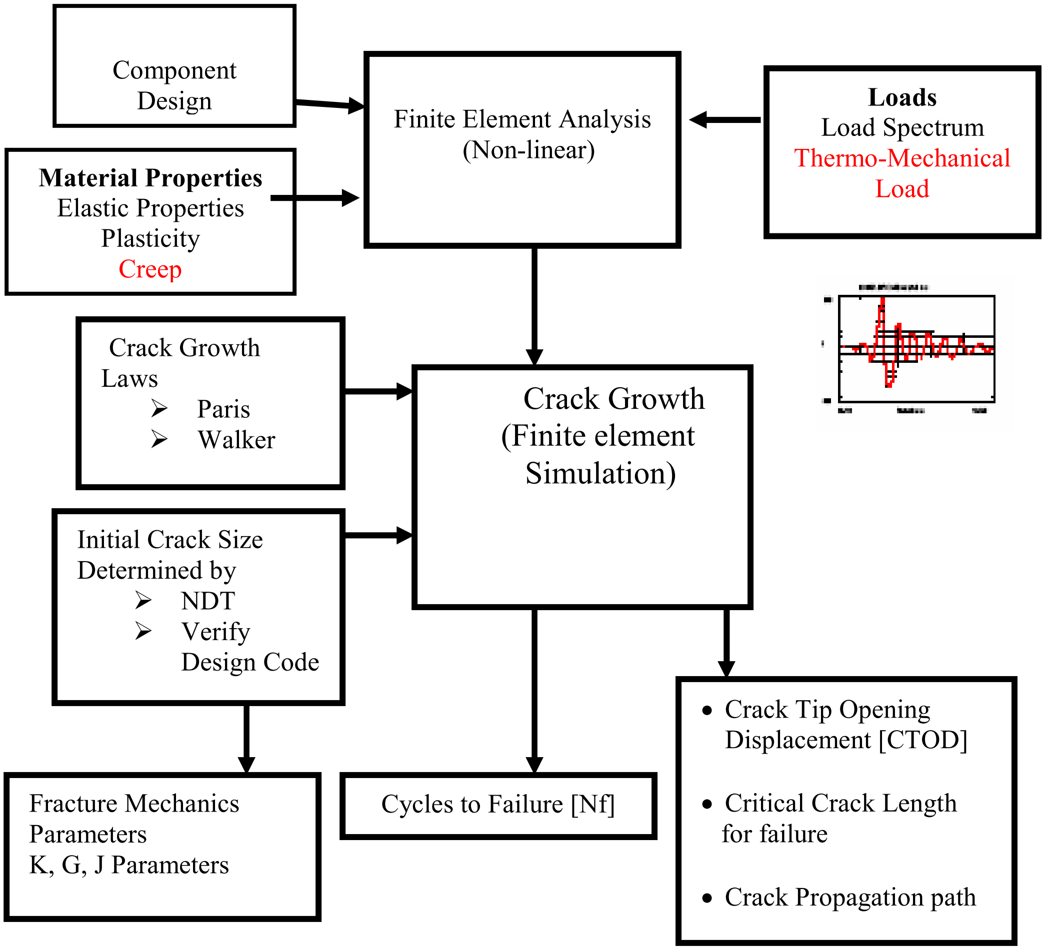
**Summary:**

In the increasingly cost-competitive deregulated utility environment, accurate and timely information on equipment condition is vital for input to repair/replacement outage planning/scheduling. By automating the process of computing damage accumulation, crack growth and remaining life, and basing these calculations on actual plant operating conditions, FEMA offers utilities many benefits:

- By taking periods of low-stress operation into account, FEMA provides more accurate damage predictions than those based on maximum design or operating conditions, thus enabling utilities to significantly reduce inspection frequency and extend the useful life of critical components.
- Advanced data trending and analysis tools operators to identify and adjust plant operating procedures to minimize creep and fatigue damage at locations with higher/abnormal damage accumulation rates, thereby avoiding unnecessary component degradation. The effect of revised operating procedures can also be evaluated using off-line simulations.
- When a crack or fabrication defect is detected during inspection, FEMA monitor results provide critical input for run/repair/replace decisions, possibly enabling utilities to avoid or delay unnecessary repairs and outage extensions. Automated tracking of damage and crack growth in critical components eliminates the need for tedious and less accurate manual calculations of remaining life.

**Flow Chart 1**

## Flow Chart to Predict the Life of High Temperature Components



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